Case Report

Seatbelt submarining injury and its prevention countermeasures: How a cantilever seat pan structure exacerbate submarining

Chandrashekhar K. Thorbole[1]

[1]*Director, Thorbole Simulation Technologies LLC, Rogers, Arkansas 72758, USA*

Abstract

The purpose of this study and a case report was to demonstrate seat belt webbing induced injury due to seatbelt submarining during the frontal motor vehicle crash. Submarining is an undesired phenomenon during a frontal crash scenario and is dependent on design features of the seat pan and seatbelt system. The lack of adequate anti-submarining features at any seating position with three-point restraint can cause abdominal solid and hollow organ injuries. This paper reports a case of submarining and factors that exacerbated this phenomenon leading to critical occupant abdominal injury. This case report and the following injury causation analysis demonstrate the shortcomings of a cantilever seat pan design in context to the occupant safety. The inadequate seat pan anti-submarining feature in association with lack of seatbelt load-limiter and Pretensioner reduces the level of occupant protection offered by the seat belt system in the rear seat. This case report shows the dangers of cantilever seat pan design and its association with increased risk of submarining causing severe abdominal injuries.

Keywords: Contoured seat pan, liver, load-limiter, pretensioner, submarining

Introduction

The seatbelt is the most important safety device in the vehicle protecting an occupant in every crash scenario. The National Highway Traffic Safety Administration report shows the effectiveness of seat belts in saving lives similar to many other reports and studies.[1-5] However, many have reported seatbelt induced injuries in the past.[6-8] The level of protection offered by the seatbelt is reduced if the load transfers to relatively soft anatomical regions such as abdomen and chest wall. This phenomenon is called submarining. The classical definition of submarining is "the lap belt sliding over the iliac crest with lap belt forces affecting the internal abdominal organs during the forward displacement of the lower torso."[9]

Case Report

The 61-year-old Hispanic male sustained critical abdominal and thorax injuries in the frontal crash. Figure 1 shows the crash location and vehicle orientation postcrash. He was seated in the right rear seat position of the pickup (a small truck with an enclosed cab and open back). The seat at this location featured a cantilever type seat pan structurally unsupported at the front end as shown in Figure 2. Figure 3 shows the pickup frontal damage. He was complaining, "my stomach and chest hurts" at the crash scene based on the emergency medical service responders report. This report also indicates the presence of positive lap and shoulder belt bruising on the occupant. The computed tomography (CT) scan study at the hospital revealed grade 5 liver laceration with small bowel perforation and left first, second, third and fourth rib fractures with pneumothorax as shown in Figure 4. He also sustained associated right C7 transverse process fracture with no cerebrovascular injuries. Head and neck CT studies were unremarkable. Table 1 shows his injury severity as per the Abbreviated Injury Scale (AIS) scale, and Table 2 shows several operative procedures conducted on him in the hospital. He expired after 20 days of treatments and operations in the hospital. He developed septic shock and progression of his liver failure.

Discussion

During impact, he moved forward at the initial vehicle speed due to inertia until acted upon by the lap and shoulder belt

Access this article online	
Quick Response Code:	Website: www.jfmpc.com
	DOI: 10.4103/2249-4863.174299

Address for correspondence: Dr. Chandrashekhar K. Thorbole, Thorbole Simulation Technologies LLC, Rogers, Arkansas 72758, USA. E-mail: thorsimtech@gmail.com

Figure 1: Crash location and vehicle orientation postcrash scene (Arizona police file)

Figure 3: The subject vehicle frontal crush profile (original)

Table 1: AIS for the occupant

Injury	AIS 2005
Liver laceration level 4-5	541828.5 (critical)
Mesentric avulsion	542026.4 (severe)
Perforation of small bowel	541424.3 (serious)
Necrotic omentum	542299.2 (moderate)
Left chest wall (rib fractures)	450203.3 (serious)
C7 transverse process fracture-right	650620.2 (moderate)

AIS: Abbreviated injury scale

restraining force. The left multiple rib fracture pattern with abrasion and bruising on the left chest occurred due to shoulder belt loading. The fracture pattern of the ribs is consistent with excessive anterior chest compression on the left side. The Toyota Central R and D Labs Research,[10] based on computational model, showed lateral rib fracture along the path of the diagonal belt similar to a 30 mph frontal crash scenario. Figure 3 shows the zoomed rib fracture pattern and its location. This fracture pattern supports the fact that the shoulder belt load was more directed to the chest instead of on stronger anatomical regions such as clavicle and his right shoulder. The absence of the load-limiter likely subjected his chest to higher load and increased the severity of his chest injury. Foret-Bruno *et al.*, 1998[11] showed more than 50% probability of AIS 3+ thorax

Figure 2: Second row cantilever seat pan design in the pickup involved in the crash (original)

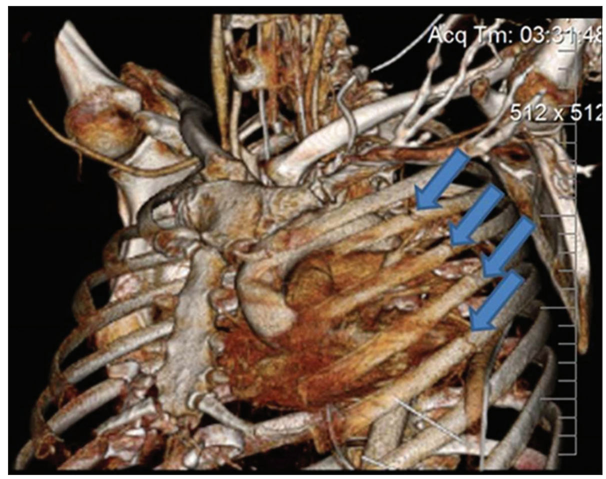

Figure 4: Rib fracture location on the left side (patient file)

injury for a 60-year-old occupant with shoulder belt load ≥5000 N (Newton). The associated right C7 transverse process fracture and absence of sternum fracture verify the shoulder belt load path, consistent with his submarining. Arndt 1975[12] reports of C7 and T1 transverse process fracture for drivers on the left-hand side due to shoulder belt contact. The absence of a load-limiter and pelvis forward and downward motion most likely caused the shoulder to lag the pelvis. This motion positioned his upper torso in a more reclined configuration as shown in Figure 5 by the unfavorable kinematics image. In the past, researchers[9,13,14] have shown the effect of these kinematics to cause the lap belt to ride over anterior superior iliac spine. This riding over cause severe loading of the abdomen, causing solid and hollow organ injuries.[15,16] The lap belt riding on the abdomen due to his submarining is the source of injury to his abdominal solid and hollow organs. The force exerted by the lap belt caused bruising on the lower and mid abdomen along with all of his internal injuries.

Car manufactures have shown the efficacy of a fixed stiff contoured seat pan structure at a rear seat location in the

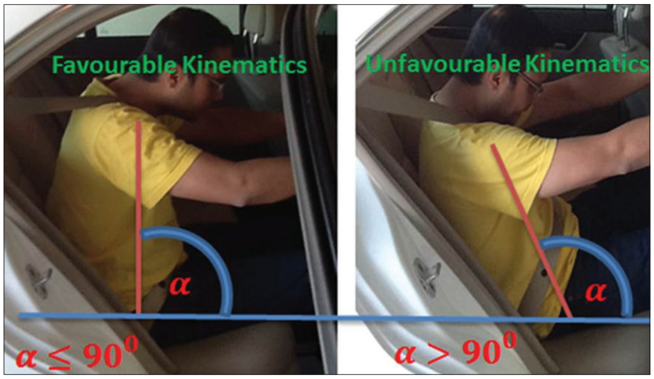

Figure 5: Example of favorable and unfavorable kinematics in a frontal crash for a belted rear seat passenger (original)

Figure 6: Investigation of the seat pan structure of the similar vehicle (original)

frontal crash in the past. This design has been shown to produce favorable occupant kinematics by preventing the pelvis from moving forward and downward reducing the risk of submarining.[17,18] High cushion thickness at the front end of the seat pan has been linked to worsening the submarining.[19] Any counter measure that ensures the upward motion of the H-point (pelvis) and the reduction of upper torso angle (getting more acute) during the forward motion of the pelvis is capable of eliminating or reducing submarining. Several United States seat pan patents demonstrate different ways of achieving this favorable pelvis kinematics.[20-22] The analysis of a seat pan structure of a similar vehicle is shown in Figure 6. The seat pan is a smooth plane stamped surface with a nonrate sensitive cushion on top of it and features a 13–14° upslope. All the features along with its overhanging structure make it less desirable for anti-submarining performance. A seatbelt equipped with a pretensioner and a load-limiter further improves the occupant kinematics by allowing forward rotation of the upper torso with adequate pelvis restraint.[23,24] William Haddon matrix, as shown in Table 3, provides an opportunity to understand the various factors influencing the outcome of a crash in different phases. This systematic approach to injury prevention is crucial to Indian conditions.[25] In the case study discussed, the vehicles cantilever rear seat design, reduced the level of occupant protection by making it unreasonably dangerous in a frontal crash scenario. During the impact phase, vehicles crashworthy performance is the single most important factor that prevents or reduces the severity of injuries to the occupants. The weather conditions during the crash were good with dry road surface and good light conditions. The posted speed limit at the crash site was 55 mph (88 kph).

Recommendation

A stiff fixed contoured anti-submarining seat pan with a seat belt equipped with load-limiter and pretensioner is the best countermeasure to tackle occupant submarining and subsequent abdominal injuries. The stiffer fixed, properly supported seat pan, instead of a cantilever seat pan would have prevented the downward deflection of the pan while the forward excursion of the pelvis. This downward dynamic deflection worsened the lap belt riding on the abdomen. This knowledge will assist Indian automotive design

Table 2: Operative procedures conducted on the occupant

Day	Operative procedures
Day of crash	Insertion of left 32-French chest tube-Left pneumothorax
	Exploratory laparotomy for trauma
	Small bowel resection × 4
	Hepatorrhaphy × 2
	Packing of liver
	Placement of wound VAC
Next day	Second-look laparotomy - Traumatic shock
	Small bowel resection
	Repacking of liver laceration
	Suture of 4+ cm liver laceration
	Repacking of liver with multiple pads
	Placement of ABThera with open abdomen
3 days after crash	Exploratory laparotomy
	Cholecystectomy
	Hepatorrhapy with wrapping of liver with Vicryl mesh
	Resection of segment of small bowel
	ABThera placement
4 days after crash	Exploratory laparotomy with removal of lap packs from around liver
	Small right colon resection with ileocolonic stapled anastomosis
	Small bowel-to-small bowel anastomosis
	Placement of ABThera for open abdomen
6 days after crash	Exploratory laparotomy with abdomen washout
	Closure of abdominal wound with ABThera
8 days after crash	Exploratory laparotomy
	Partial omentectomy
	Negative pressure therapy 20 cm × 30 cm
10 days after crash	Bronchoscopy with bronchial washing - Severe acute respiratory failure
11 days after crash	Exploratory laparotomy
	Abdominal washout
	Rectus advancement flap, right, and left
	Negative pressure therapy 20 cm by 30 cm
14 days after crash	Bronchoscopic guided percutaneous tracheostomy-Respiratory failure
15 days after crash	Central line placement

VAC: Vacuum-assisted closure

Table 3: Haddon matrix for systematic crash injury prevention

Phase	Goal	Human	Vehicle	Environment
Preimpact	Accident prevention	Education/enforcement	Accident prevention technologies	Road design, weather conditions, road surface condition (dry/wet)
Impact	Injury prevention	Using available safety system	Crashworthiness, occupant protection features	Roadside barriers
Postimpact	Life support	EMS, fire, aid	No fire risk	Quick rescue facility

EMS: Emergency medical service

engineers to develop a more effective injury prevention scheme for rear seat passengers. Emergency medical responders will also benefit from this study by identifying and understanding the submarining and suspecting serious underlying abdominal injuries. This knowledge facilitates in prompt diagnosis and treatment of injuries.

Conclusion

The downward dynamic deflection of the rear seat pan and the unavailability of advanced seat belt features such as load-limiter and pretensioner are the fatal injuries producing cause in the crash investigated. The study explains the injury mechanism and countermeasures to prevent such injuries. The occupant died due to his abdominal injuries after 20 days in the hospital.

Acknowledgment

The author gratefully acknowledges the consent of a family member for the publication of this case study.

References

1. National Highway Traffic Safety Administration. "Lives Saved in 2008 by Restraint Use And Minimum Drinking Age Laws (Report No. DOT HS 811 153)." Washington, DC: US Department of Transportation; 2010.
2. Glassbrenner D, Starnes M. Lives Saved Calculations for Seat Belts and Frontal Air Bags. No. HS-811 206. 2009.
3. NHTSA Report "Safety in Numbers", Volume 1, Issue 2, May, 2013. Available from: http://www.nhtsa.gov/nhtsa/Safety1nNum3ers/
4. World Health Organization. Seat-Belts and Child Restraints: A Road Safety Manual for Decision-Makers and Practitioners. London: FIA Foundation for the Automobile and Society; 2009.
5. Thorbole CK, Renfroe DA, Batzer SA, Beltran D, Herndon G.Computational Analysis of a Near and Far Side Front Occupant Kinematics in a Vehicle Rollover with Different Restraints. Enhanced Safety Vehicles, Stuttgart, Germany; 2009.
6. Anderson PA, Rivara FP, Maier RV, DRAKE C. The epidemiology of seatbelt-associated injuries. J Trauma Acute Care Surg 1991;31:60-7.
7. Agrawal A, Inamadar PI, Subrahmanyam BV. Seat belt sign and its significance. J Family Med Prim Care 2013;2:288-90.
8. Asbun HJ, Irani H, Roe EJ, Bloch JH. Intra-abdominal seatbelt injury. J Trauma Acute Care Surg 1990;30:289.
9. Dieter A, Heger A. Motion Sequence Criteria and Design Proposals for Restraint Devices in Order to Avoid Unfavourable Biomechanic Conditions and Submarining. No. 751146. SAE Technical Paper; 1975.
10. Leung YC, Tarriere C, Lestrelin D, Got C, Guillon F, Patel A. *et al.* Submarining Injuries of 3-Point Belted Occupants in Frontal Collisions-Description, Mechanisms and Protection." Proceedings: Stapp Car Crash Conference. Vol. 26. Society of Automotive Engineers SAE; 1982.
11. Leung YC, Tarriere C, Fayon, A, Mairesse P, Banzet P. An Anti-Submarining Scale Determined from Theoretical and Experimental Studies Using Three-Dimensional Geometrical Definition of the Lap-Belt. No. 811020. SAE Technical Paper; 1981.
12. Tamura A, Watanabe I, Miki K. Elderly Human Thoracic FE Model Development and Validation. Proceedings of the 19th ESV Conference, European Enhanced Safety of Vehicle; 2005.
13. Foret-Bruno JY, *et al.* Thoracic Injury Risk in Frontal Car Crashes with Occupant Restrained with Belt Load Limiter. No. 983166. SAE Technical Paper; 1998.
14. Arndt RD. Cervical-thoracic transverse process fracture: Further observations on the seatbelt syndrome. J Trauma Acute Care Surg 1975;15:600-2.
15. Holbrook TL, Lisa T, Hoyt DB, Eastman AB, Sise MJ, Kennedy F, *et al.* The impact of safety belt use on liver injuries in motor vehicle crashes: The importance of motor vehicle safety systems. J Trauma Acute Care Surg 2007;63:300-6.
16. Smith JE, Hall MJ. Injuries caused by seatbelts. Trauma 2005;7:211-5.
17. Lundell B, Mellander H, Carlsson I. Safety Performance of a Rear Seat Belt System with Optimized Seat Cushion Design. No. 810796. SAE Technical Paper; 1981.
18. Haberl J, Eichinger S, Werner W. New Rear Safety Belt Geometry – A Contribution to Increase Belt Usage and Restraint Effectiveness. No. 870488. SAE Technical Paper; 1987.
19. Prasad A, Weston D. NHTSA's Rear Seat Safety Research. Proceedings of the 22nd Enhanced Safety of Vehicles Conference. Washington, DC: NHTSA; 2011.
20. Yamaguchi H, Shono H. Anti-Submarine Vehicle Seat Device. U.S. Patent No. 6,450,573. 17 Sep, 2002.
21. Park MK. Anti-Submarine Seat for an Automobile. U.S. Patent No. 6,672,667. 6 Jan, 2004.
22. John C. Deformable Seat Pan for a Tiltable Vehicle Seat. U.S. Patent No. 8,240,758. 14 Aug, 2012.
23. Michaelson J, Forman J, Kent R, Kuppa S. Rear seat occupant safety: Kinematics and injury of PMHS restrained by a standard 3-point belt in frontal crashes. Stapp Car Crash J 2008;52:295-325.
24. Forman J, Michaelson J, Kent R, Kuppa S, Bostrom O. Occupant Restraint in the Rear Seat: ATD Responses to Standard and Pre-Tensioning, Force-Limiting Belt Restraints. Annals of Advances in Automotive Medicine/ Annual Scientific Conference. Vol. 52. Association for the Advancement of Automotive Medicine; 2008.
25. Chandrashekhar T, Girikumar K, Sagar B. Traffic Accident Injury Causation Analysis for Implementing Injury Prevention Strategies in India Technical Reference Bulletin, Symposium on International Automotive Technology, Pune, INDIA; 2015.

How to cite this article: Thorbole CK. Seatbelt submarining injury and its prevention countermeasures: How a cantilever seat pan structure exacerbate submarining. J Family Med Prim Care 2015;4:587-90.

Source of Support: Nil. **Conflict of Interest:** None declared.